SMAST Sea scallop (*Placopecten magellanicus*) drop camera survey from 1999 to 2014

Kevin D. E. Stokesbury, Erin K. Adams, Samuel C. Asci, N. David Bethoney, Susan Inglis, Tom Jaffarian, Emily F. Keiley, Judith M. Rosellon Druker, Richard Malloy Jr., Catherine E. O'Keefe

Department of Fisheries Oceanography,
School for Marine Science and Technology, University of Massachusetts Dartmouth,
200 Mill Road, Suite 325, Fairhaven, Massachusetts,
02719
Phone: (508) 910-6373
Fax: (508) 999-8197
Email: kstokesbury@umassd.edu

Summary of the existing state of knowledge related to the project: The US sea scallop fishery is managed under an area rotation system requiring spatially-specific information on scallop density and size. The SMAST drop camera survey provides this type of information with high levels of accuracy and precision. Since 1999, SMAST has completed >175 cruises surveying Georges Bank and the Mid-Atlantic (>1000 days at sea), with support from the commercial sea scallop industry, the Massachusetts Division of Marine Fisheries, the Massachusetts Marine Fisheries Institute and the sea scallop Research Set Aside program. This unique database covers the entire scallop resource (~70,000 km^2) from 2003 through 2012 and in 2014. Further, it includes numerous finer scale surveys focusing on scallop aggregations primarily in closed areas of Georges Bank and the Mid-Atlantic. Survey data have been incorporated into the scallop stock assessment through the Stock Assessment Workshop (SAW) process and have been reliably provided to the New England Fisheries Management Council (NEFMC) Scallop Plan Development Team (PDT) annually by the first of August for inclusion in the management arena; our 2014 data were formally requested by the executive director of the NEFMC in an email on 20 August 2014.

Outreach and education: Our research on the sea scallop population influences fisheries management, including conservation of the stock and the scallop fishing industry in a positive and constructive manner. To ensure that we are conducting research that is "the best available science" we have published the protocols and analyses from our survey; a list of our publications related to scallops and the drop camera survey is provided as Support Document 1. We have regular meetings with our Scallop Industry Steering Committee made up of fishermen, vessel owners, and scallop processors. This steering committee discusses management issues, the needs and concerns of industry, our ongoing research and future goals. Presently there are 5 graduate students whose research is supported by our scallop database; 8 graduate students have successfully completed degrees. We participate annually in the Working Waterfront Festival and the Massachusetts High School Marine Science Symposium. Our faculty, students, and staff are committed to presenting this research to the general public particularly primary, middle and high-school students. We have worked to develop education programs with the Ocean Explorium and the National Science Foundation funded TEACH! South Coast initiative.

SMAST Drop Camera Goals, Objectives and Deliverables:

Our goal for the SMAST drop camera survey is to provide fishery resource managers, marine scientists and fishing communities with an independent assessment of the US sea scallop resource and its associated habitat. The survey design, including precision between stations on 1.6 km and 5.6 km scales, quadrat size and protocols, are published in Stokesbury, 2002 (Support Document 2) and Stokesbury et al., 2004 (Support Document 3). Further examination of accuracy on different spatial scales and geostatistics on scallop aggregation structure are published in Adams et al., 2008 (Support Document 4) and 2010 (Support Document 5).

Objectives and Deliverables:

- Spatially-Specific Estimates of Absolute Scallop Density: Evaluate scallop density throughout the resource range on Georges Bank and the Mid-Atlantic using counts and shell heights from the SMAST drop camera survey. The data products include: 1) estimates and maps of scallops in the scallop resource; and 2) estimates of associated error and variance. This can be partitioned into the closed and open areas and identifies areas of new recruitment.
- Spatially-Specific Estimates of Scallop Total and Exploitable Biomass: Evaluate scallop biomass throughout the resource range on Georges Bank and the Mid-Atlantic using shell height measurements from the SMAST drop camera survey. The data products include: 1) mean meat weight (g) of individuals over entire range of scallop resource; and 2) estimates of total and exploitable biomass of scallops derived from area-specific shell height to meat weight relationships and commercial dredge selectivity equations (NEFSC, 2010). This can be partitioned into the closed and open areas to estimate specific total allow catch by area.
- Spatial structure of substrate characteristics, seabed disturbance and the abundances and densities, or presence/absence of macrobenthos. Provide accurate, georeferenced data and maps of the western North Atlantic continental shelf benthos. These data contribute to the SMAST data-base and are used to update several ecosystem based management activities including the NEFMC Swept Area Seabed Impact model (NEFMC, 2011a). The information is also used to develop geological and biological assemblages for the Gulf of Maine, Georges Bank and the Mid-Atlantic Bight, and in conjunction with the Bureau of Ocean Energy Management, the Cooperative Institute for the North Atlantic Region and the National Marine Fisheries Service to assess windfarm development impacts on the US continental shelf.

ToR 1. Review the statistical design and data collection procedures for each survey system

Project design and management: Approximately 2,000 stations are sampled between April and July each year in a centric systematic sampling design (Figure 1). The drop camera sampling pyramid is deployed from scallop fishing vessels, which to date have been donated for this research (Figure 1; Stokesbury, 2002, Stokesbury et al., 2004). A complete list of donors is provided in Support Document 6. We shift the survey grid annually to increase the spatial resolution of the survey and avoid potential systematic bias in the survey time series as recommended by the Northeast Fisheries Science Center (NEFSC) Stock Assessment Review Committee (SARC).

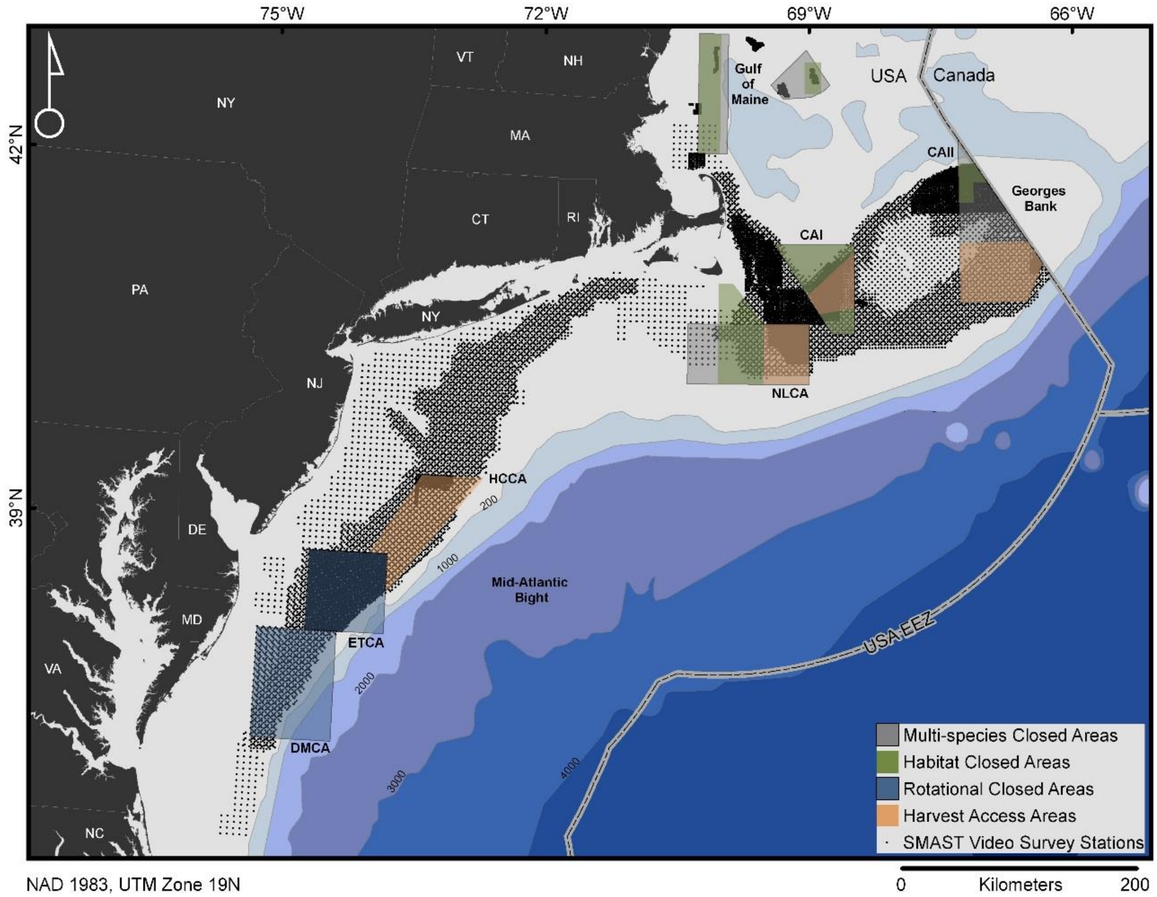

Figure 1. The SMAST drop camera survey of the Mid-Atlantic and Georges Bank sea scallop resource surveyed from 1999 to 2014. The annual continental shelf-scale survey stations (5.6 km grid), and the high resolution survey stations (1.6 and 2.2 km grids) appear in black areas, each station represents 4 deployments of the drop camera pyramid.

Selection of station spacing:

Stokesbury (2002) describes the preliminary survey to test the video equipment and explore variability in scallop density and abundance estimates. This preliminary survey estimated scallop densities within a small region (55 km^2) of the Nantucket Lightship area identified by fishermen as supporting very high densities of sea scallops. Eighteen randomly selected stations were sampled. The fishing vessel was anchored on station and the video camera mounted on the sampling pyramid was lowered to the sea floor and then retrieved. Approximately 10 m of anchor line was released and the pyramid was deployed and retrieved until 10 quadrats of the sea floor had been collected. A quadrat is an image of the sea floor collected at a station. The preliminary survey indicated that the sampling technique was adaptable to fishing vessels, and provided precise estimates of scallop density (18 stations, 10 quadrats per station, mean number of scallops per 1.0 m^2 quadrat = 1.2, SE = 0.41).

The variance to mean ratio estimated from the preliminary study suggested that the sea scallops had a Poisson distribution within the sampled area (12.6 with 9 degrees of freedom). This ratio and the Poisson distribution indicated that the precision would be improved with fewer quadrats at each station and more stations, for example, 7 to 187 stations were required for 25% to 5% precision assuming an approximately normal distribution. However, sea scallops are usually aggregated rather than randomly distributed on the sea floor. If this is the case the number of stations increases greatly to obtain the same level of precision. The negative binomial distribution describes an aggregated distribution and has described scallop distributions in other locations (Stokesbury and Himmelman, 1993). Using the mean and variance from the preliminary study provides a k value of 3.0 (k is the negative binomial exponent). Modifying equation 1 with a negative binomial distribution 75 to 1868 stations are required for 25% to 5% precision (Krebs, 1989). Based on these estimates approximately 200 stations in the northeastern corner of the Nantucket Lightship area would provide estimates of scallop density with 5% to 15% levels of precision for the normal and negative binomial distributions, respectively.

As described in Stokesbury et al. (2004) the survey was expanded to cover the entire sea scallop resource on Georges Bank and the Mid-Atlantic. Stations were positioned on a 5.6 by 5.6 km (3.0 by 3.0 nautical mile) grid overlying historical and present fishing grounds based on information from commercial fishermen and the Vessel Monitoring System (Rago et al., 2000). We selected the distance of 5.6 km between stations because it was logistically feasible and allowed an accurate estimate of the mean sea scallop density with little loss of precision. Estimates of mean sea scallop•m^{-2} from the Nantucket Lightship area, surveyed in 2002, were similar for distances between stations ranging from 1.6 to 5.6 km; the standard error increased due to reduced sample size but the coefficients of variation (CV) were still low, 0.62 (SE = 0.057, CV = 9.3%) and 0.62 (SE = 0.101, CV = 16.3%) scallop•m^{-2}, respectively. For distances greater than 5.6 km between stations the estimated means of scallop•m^{-2} as well as the standard errors and coefficients of variation increased, for example the mean was 0.75 scallop•m^{-2} (SE = 0.300, CV = 40.1%) for a 9.3 km station grid.

In 2006 two independent video surveys of sea scallop (*Placopecten magellanicus*) abundance were done in the Elephant Trunk Closed Area offshore of the eastern US: one using a 5.6 by 5.6 km grid and the other using a 2.2 by 2.2 km grid. Adams et al. (2008) generated a kriged surface of sea scallop abundance using the larger grid data, and compared these predicted values with the actual scallop counts observed at the finer scale grid stations. Kriging with a spherical fit to a classical semivariogram gave the best approximation to the arithmetic mean abundance obtained with the finer scale survey. Alternatively, kriging with an exponential fit to a classical semivariogram yielded the most realistic spatial structure for normalized, de-trended data. In the latter case use of a robust semivariogram detailed the spatial structure and gave increased maximum values, albeit with more negative predictions. Adams et al. (2008) concluded that SMAST 5.6 km grid video data can be used in the original units to generate kriged means that will approximate the true mean of finer scale surveys.

Selection of systematic vs random stratified sampling

We used a centric systematic design to position the stations as it is simple, samples evenly across the entire survey area, and has been successfully used to survey scallops on Georges Bank

(Thouzeau et al., 1991, Stokesbury, 2002). With this sampling design it is possible to estimate densities of macroinvertebrates within different areas without violating the sampling protocol or paying a statistical penalty for post-stratification. Further the centric systematic design facilitates mapping sea floor sediments and macroinvertebrate distributions (Stokesbury et al., 2004). Both Cochran (1977) and Rivoirard et al. (2000) suggest the systematic design is superior, particularly when distributions are patchy. However this issue is still continually debated for surveys.

To further verify this sampling protocol we conducted a six day survey to the Nantucket Lightship area in June 2006. Two of our 31 km^2 sample areas were inside the Nantucket Lightship area and two were outside so that we surveyed both a high and low density of scallops. We compared a multistage centric systematic survey on two spatial scales (1.57 km and 5.6 km) to a simple random survey with 300 stations. These designs allowed a number of different statistical comparisons between the two survey designs including comparisons of densities and size frequencies of sea scallops, other macroinvertebrate and sediment compositions. The results were presented in Research Set Aside final report NMF4541295 (Support Document 7). There were no significant differences between the scallop density estimates obtained from the 3 survey designs ($p = 0.627$; Table 1). The macrobenthos observed in the grid surveys were also similar to the random stations (>79% similarity).

Table 1. The number of stations sampled in the random, 1.57 km and 5.6 km grid surveys, numbers of scallops counted, mean number of scallops m^2, standard error (SE) and coefficient of variation (CV%).

Survey	Stations	Scallops	Scallops m^{-2}	SE	CV%
Random	304	511	0.52	0.046	8.936
1.57 km grid	49	392	0.62	0.133	21.453
5.56 km grid	4	40	0.77	0.319	41.231

Selection of Quadrat areas:

When we began this research in 1999, the resolution of the quadrat images indicated that a size of 2.8 m^2 provided the most information on scallop distribution (Stokesbury, 2002). The upper limit of quadrat size was restricted by visibility; 2.8 m^2 was the largest area that provided a clear image of the sea floor given the conditions on Georges Bank. Scallops within the viewing field and those along the edge were counted so the sample area was increased to 3.235 m^2 to correct for edge bias (Krebs, 1989; see ToR 2 "*Edge effect for video counts*").

In its present configuration two downward looking live feed video cameras and a digital still camera provide three quadrats with 2.8 m^2, 0.60 m^2, and 1.06 m^2 views, respectively, of the sea floor. A fourth live feed video camera provides a horizontal view across the sea floor. We integrate and calibrate new camera equipment as it is developed for use in this survey, however, we have maintained the original quadrat size of 2.8 m^2 for comparison throughout our time series (Figure 2).

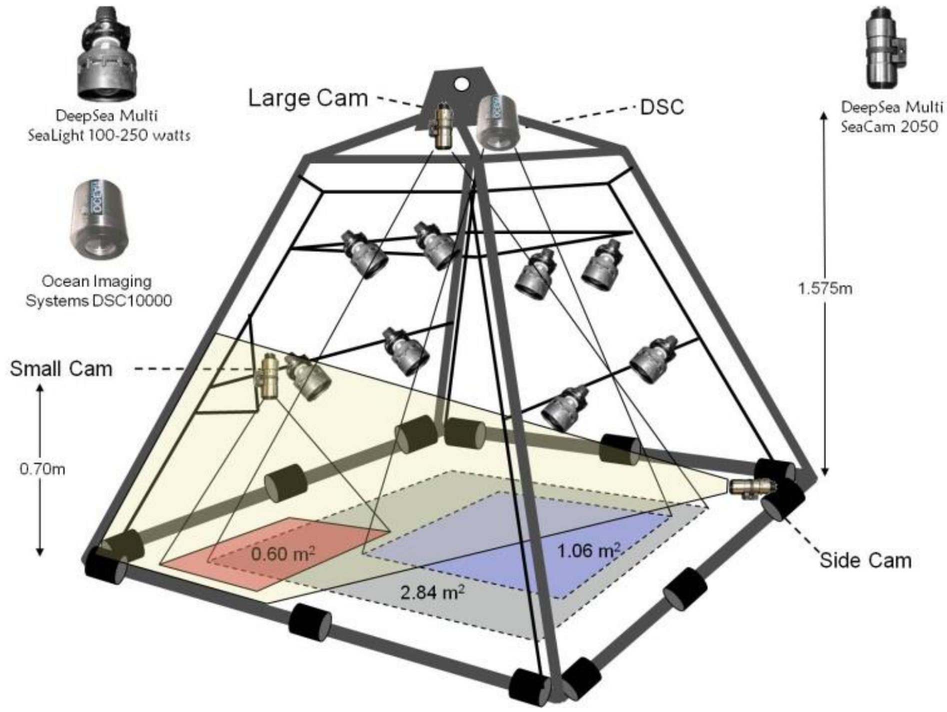

Figure 2. SMAST drop camera survey pyramid (including lights, video cameras, a digital still camera) providing three quadrat views.

Selection of number of quadrats per stations:

Sea scallops aggregate on the scale of centimeters and one scallop in 3.235 m^2 is considered a high density (0.31 scallops•m^{-2}; Brand, 1991, Stokesbury and Himmelman, 1993). By increasing the number of quadrats to four per station the observed sample area increased to 12.94 m^2 thereby greatly increasing the chance of sampling a scallop if any are located at a station (0.08 scallops•m^{-2} is below sustainable commercial density; Brand, 1991). Further, the time required to sample four quadrats at each station is minimal compared to the deployment and retrieval of the sampling gear and moving the vessel to the next station (Stokesbury, 2002, Stokesbury et al., 2004).

Data processing at sea and in the laboratory:

A mobile studio is assembled in the wheelhouse of each survey vessel. This studio includes monitors and DVD recorders for each live camera, a DVR, a monitor for the Captain, a laptop computer with Arcpad GIS® software integrated with a differential global positioning system, and a laptop computer for data entry. The survey grid is plotted prior to the cruise in Arcpad GIS®. Two scientists, a captain, mate and one deck-hand are able to survey about 50 stations every 24 hours on the 5.6 km grid.

Survey data for substrate type, presence of macrobenthos and scallop counts, as well as time, depth and location, are recorded and saved through custom software into a SQL Server Database (Figure 3). After each survey, the video footage is reviewed in the laboratory and a still image of each quadrat is digitized and saved. Within each quadrat, scallops and other macrobenthos are counted, scallops are measured and the substrate are identified (Figure 4; Stokesbury, 2002, Stokesbury et al., 2004). Each digitizer receives thorough training on the image analysis process. Training includes a self-guided 160 slide Power Point tutorial that provides detailed protocol descriptions and an identification key tailored to how species are seen in the drop camera survey. Digitizers must pass an image processing test after completing the training. The results of the test are reviewed during an in person tutorial of the Digitizing and Image Pro Plus® softwares.

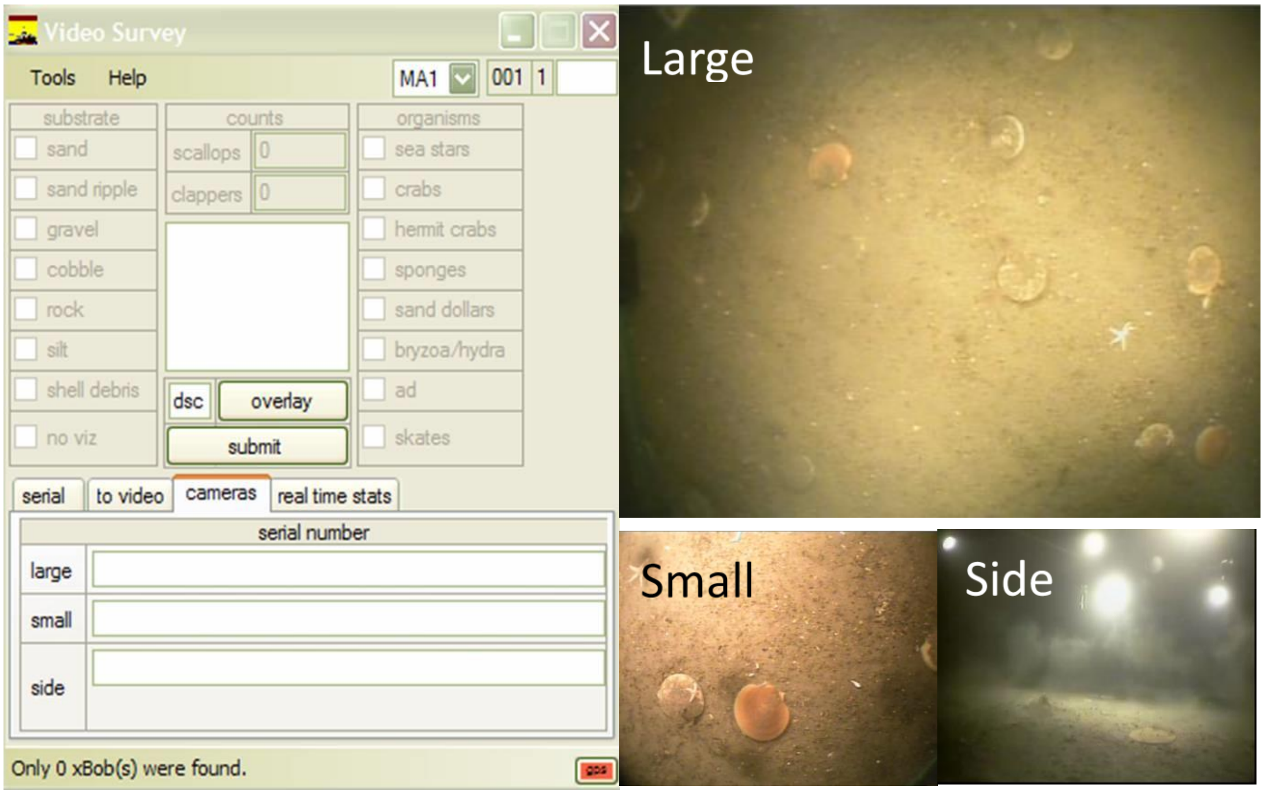

Figure 3. A custom application was created for the field-deployed studio, which controls the integrity (e.g. forces field technician to adhere to sampling rules) of data collection and inserts the data directly into the laptop instance of SQL Server. The custom field application controls the input of data including counts of scallops and clappers, presence/absence of other macroinvertebrates, and substrate. Data are collected while simultaneously viewing the large, small and side camera images.

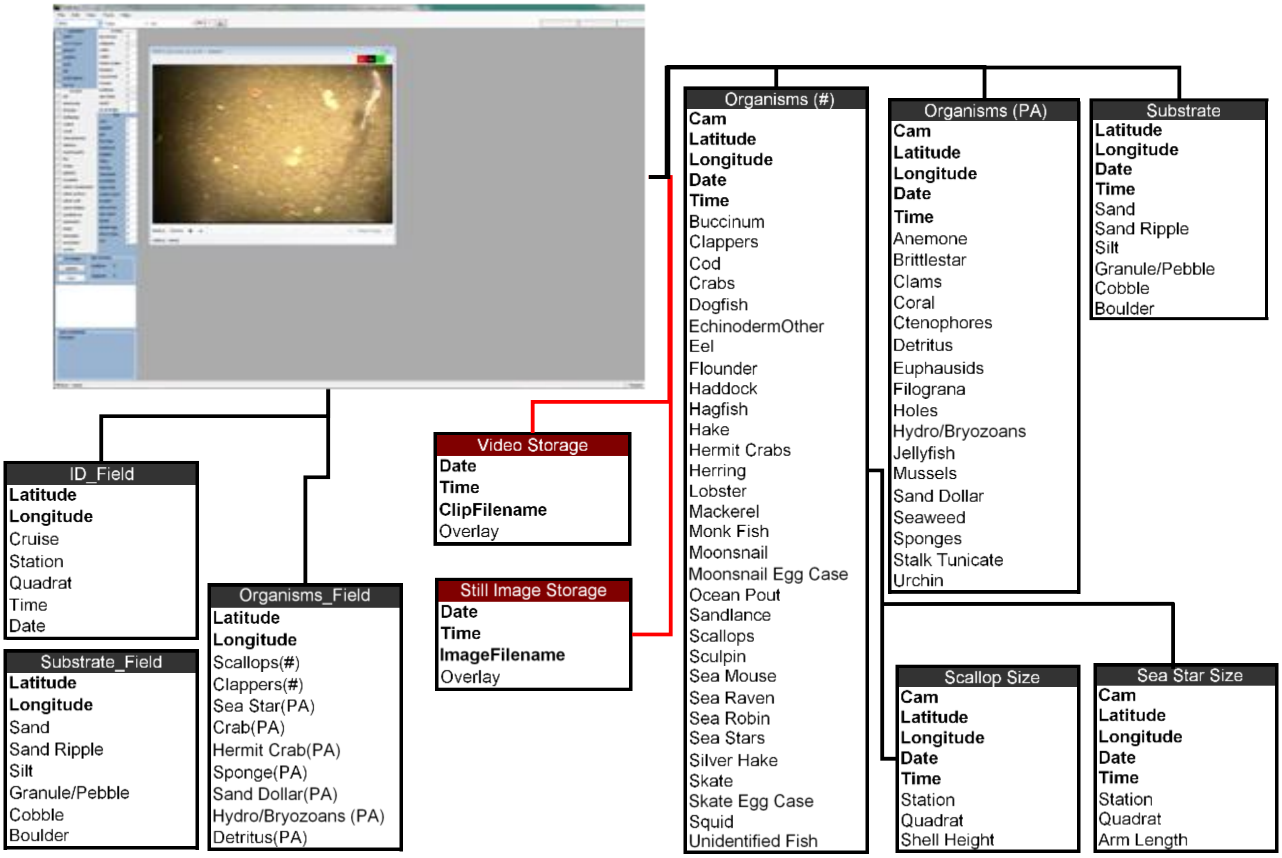

Figure 4. The Digitizer (upper left) incorporates the field data (lower left) for more precise and expanded analyses and populates the tables on the right. Data are retrieved with views, stored procedures and ad hoc queries.

After the images have been digitized, each image is checked for accuracy of counted and identified species through the “imagecheck’ profile in the Digitizer which allows for easy correction of detected errors by a senior technician (Figure 5). Images that contain scallops are extracted and converted to a format that can be measured using Image Pro Plus® software (Figure 6). In total, all images are reviewed at least three times and with images containing scallops reviewed a fourth time.

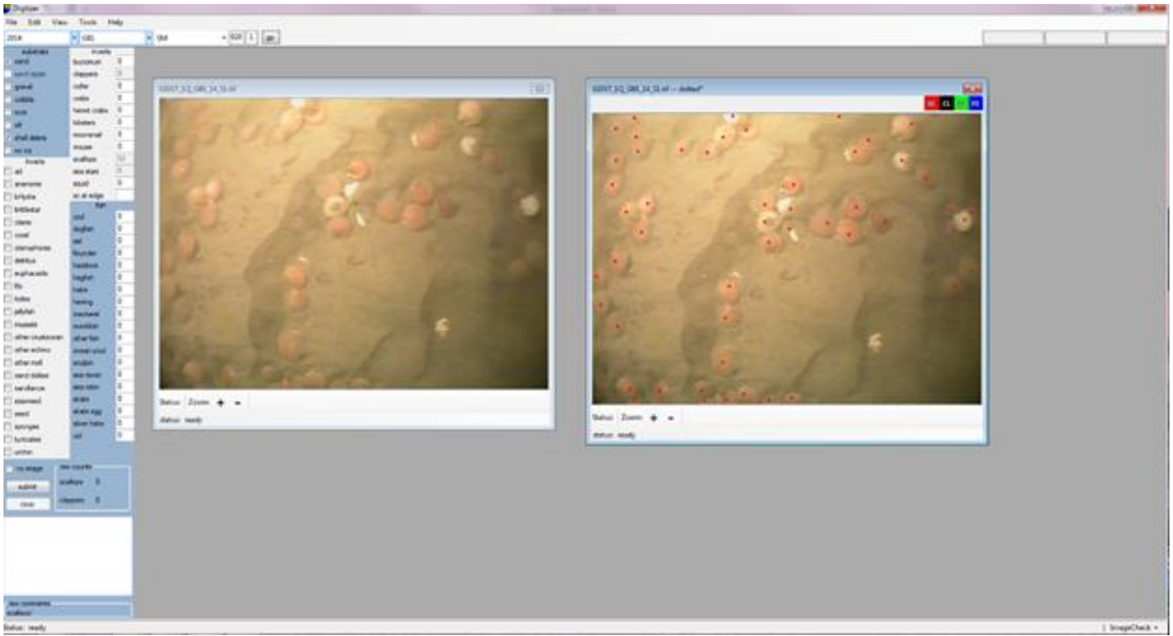

Figure 5: The Digitizer application allows the user to input updated data directly into the running database. Scallops are dotted (right), rather than counted by the user, to enhance data integrity.

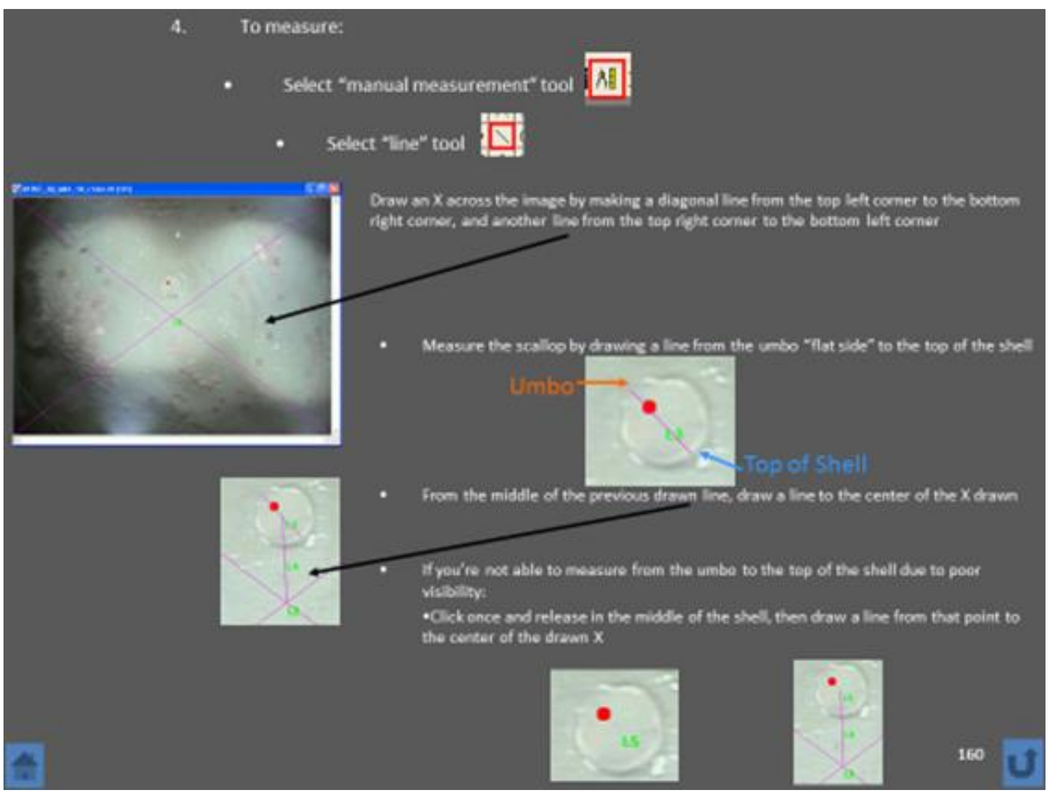

Figure 6: The measuring macro is used with Image Pro Plus® to link the shell height measurements directly to the database.

ToR 2. For each survey, evaluate measurement error of observations including shell height measurement, detection of scallops, determination of live vs. dead scallops, selectivity of gear, and influence of confounding factors (e.g., light, turbidity, sea state, tide etc.)

One of the benefits of the drop camera system is that it can be calibrated and measurement errors can be estimated in the test tank at SMAST. The system can be set up just as it is at sea and different grids or shell configurations can be analyzed. This is not easily accomplished with moving sampling gear. Calibration experiments are continually repeated and updated as new camera technology is added to the SMAST drop camera survey.

Shell height measurements

The accuracy and precision of measuring scallop shell height by video was questioned in one of the earlier scallop Stock Assessment Review Committees. In response, with NMFS scientists, we conducted a series of experiments on video large camera and NMFS protocols published in Jacobson et al., 2010 (Support Document 8). These experiments compare the measurements we obtain through the drop camera system to scallops measured with calipers or a measuring board (Figure 7).

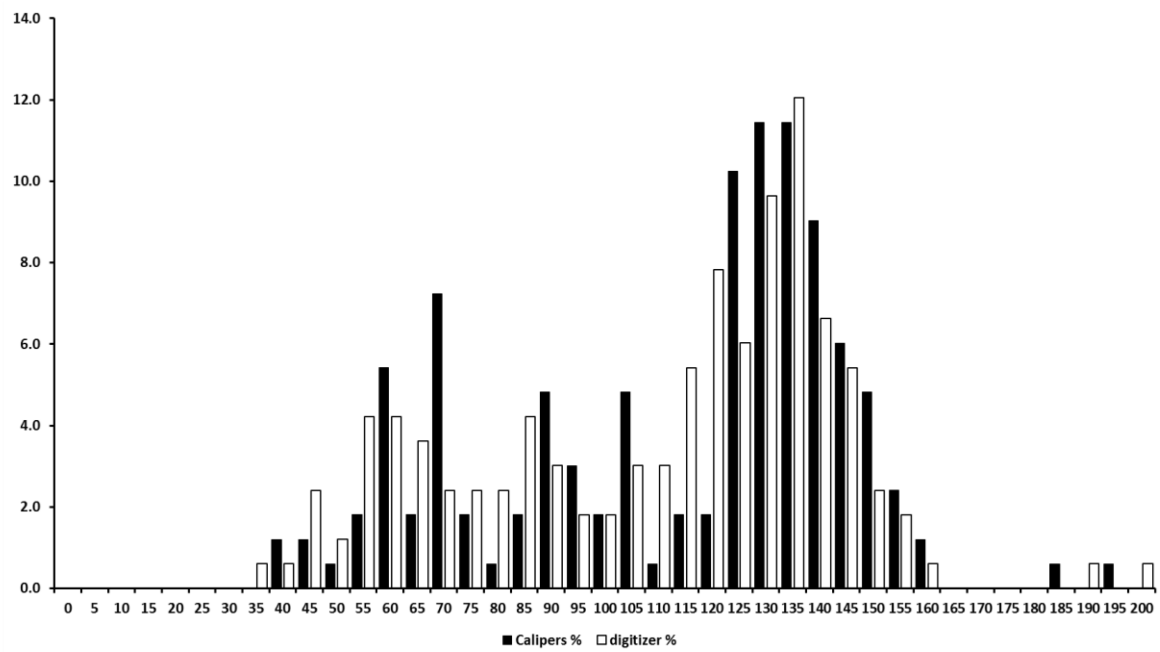

Figure 7. Comparison of scallop shells measured with the SMAST drop camera system to measurements taken with calipers; percentages per 5 mm bin, n = 166; for the calipers mean shell height was 111.5 mm SD = 32.67; for the drop camera mean shell height was 107.5, SD = 33.03.

The results from these experiments suggest that digital shell height measurements for sea scallops with true sizes evenly distributed over 100-104.99 mm shell height (i.e. the 100 mm bin with midpoint 102.5 mm) would fall into nine observed shell height bins with midpoints from 77.5 to 117.5 mm (Table 4 in Jacobson et al., 2010). Measuring board shell height measurements would fall into five observed shell height bins with midpoints ranging from 92.5 to 112.5mm (Table 4 in Jacobson et al., 2010). These results were included in CASA model runs and continue to be used.

Hart et al. (2013) state that “the (CASA) model accommodates measurement errors in shell heights, survey and landings data (Jacobson et al., 2010).” This statement is not completely accurate as Jacobson et al., 2010 compared video and measuring board data for the same scallops only; dredge surveys and landing data include scallops only once they have been placed on the deck of the vessel. There is no estimate of the impact of dredge selectivity on measurement error (what the dredge samples compared to what is actually on the sea floor) in Jacobson et al. (2010). We have been conducting a number of experiments comparing digital to actual shell height measurements that include dredge selectivity on Georges Bank and in Canadian waters on fine scales (km^2). Results from these recent experiments suggest that estimated frequencies, and mean shell heights are similar (Table 2; Figure 8). Further research on dredge/camera selectivity is discussed in ToR 7 and below.

Table 2. The number of shells measured, mean shell height (mm) and standard deviation of scallops sampled in a scientific dredge and with the SMAST drop camera survey in September 2014 on Georges Bank (GB) and two different areas of Browns Bank (BB, BB2).

	Dredge Collections				Video collections		
	n	mean	SD		n	mean	SD
GB	2230	87.2	18.38		839	90.1	21.11
BB	7576	69.1	16.37		3587	69.5	20.19
BB2	5330	65.0	21.62		3784	65.1	22.70

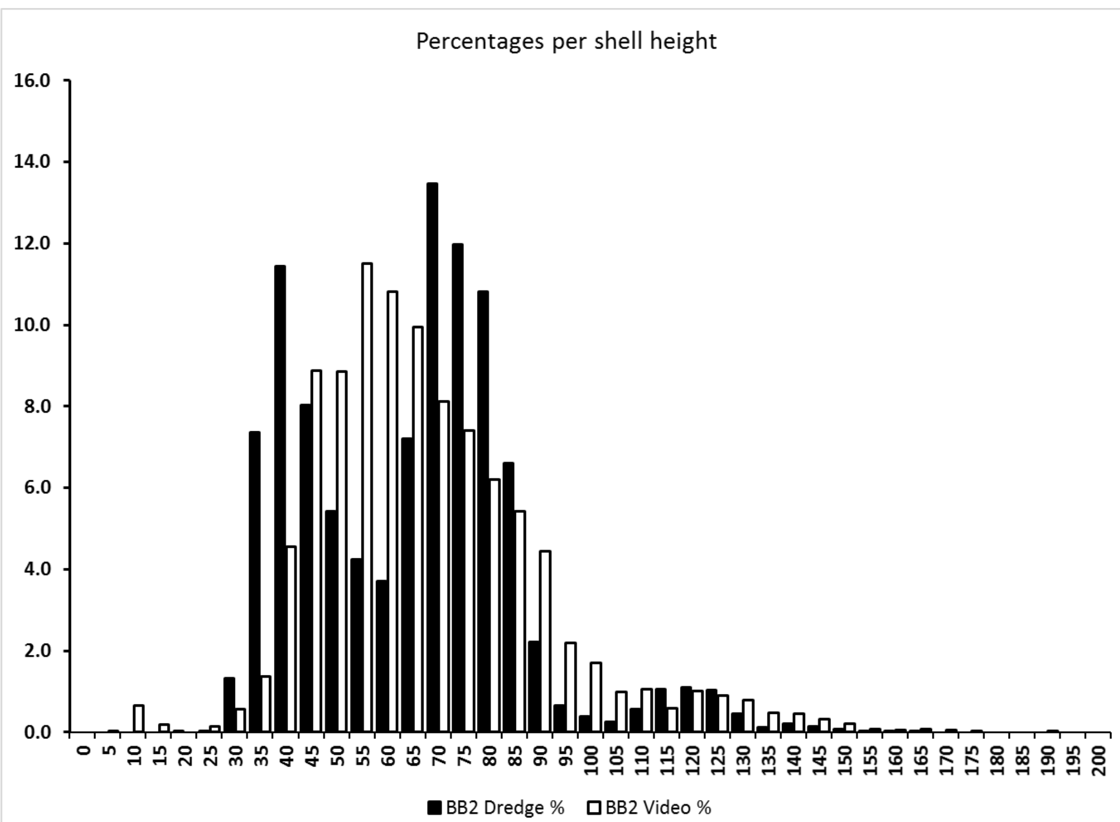

Figure 8. Comparison of shell height (mm) frequencies between dredge samples and video measures on Browns Bank (BB2).

Detection of scallops

Selectivity and efficiency of the data from the SMAST drop camera system were evaluated in SAW 45 (Marino et al., 2007a [Support Document 9]). Selectivity curves were estimated for sea scallops in the large camera using Millar's maximum likelihood SELECT model (Millar and Fryer, 1999) and the small camera as a standard measure of sea scallop length composition and density at study sites. Estimates for Georges Bank and Mid-Atlantic Bight combined during 2003-2006 indicate that the large camera system has an increasing logistic selectivity pattern for sea scallops with selectivity ≥ 50% at 48+mm, ≥ 90% at 71+ mm and ≥ 95% at 79+mm shell heights (approximate SE 1.7 mm for all estimates), and that the large camera has 100% detection probability for large fully selected scallops in its sample area (Table 3; Marino et al., 2007a).

Table 3. Average values for selectivity parameters p,a,b,L_{95}, L_{90}, L_{50}, and SR with standard errors, variances, CVs and 90% confidence intervals from SELECT models fit to large and small camera video data collected during 2003-2006 on Georges Bank and in the Mid-Atlantic (from Marino et al., 2007a; NEFSC, 2007).

n=4 for experiment from 2003- 2006

	Split (%)	L95(mm)	L90(mm)	L50(mm)	SR(mm)	a	b
Average	84.15	79.43	71.41	47.71	23.44	-4.84	0.10
Var	1.87E-05	2.867	2.867	2.867	11.207	0.457	0.000
SE	0.004	1.693	1.693	1.693	3.348	0.676	0.017
CV	5.14E-05	0.021	0.024	0.035	0.143	-0.140	0.163
CI90	0.008	3.319	3.319	3.319	6.561	1.325	0.033
Upper	84.16	82.75	74.73	51.03	30.01	-3.52	0.14
Lower	84.14	76.11	68.09	44.39	16.88	-6.17	0.07

Determining live vs. dead scallops

The method for determining live vs. dead scallops is published in Stokesbury et al., 2004 and 2007. The side camera views aids greatly with the identification of clappers (Figure 9).

Figure 9: Side camera view of a drop camera station showing a clapper among live scallops.

Selectivity of Different Cameras:

Prior to the 2010 survey, we upgraded the digital still cameras to improve image resolution. Electronics within the camera housings were reconfigured to accommodate a 12.3 megapixel Nikon D90 (Carey and Stokesbury, 2011[Support Document 10]). On 9 March 2010 we conducted a calibration experiment in the SMAST test tank and determined the view area and measurement calibration of the new cameras, allowing density estimates and measurements. We conducted an analysis comparing the ability of the large video camera, small video camera and digital still camera to detect scallops across their size range. We created density profiles by sorting the shell height data into 10 mm bins and calculating the density of scallops per m^2 for each bin. Results indicated that the detection limit of small scallops was 30-40 mm and 20-30 mm for the large and small video cameras, respectively, while scallops as small as 10 mm were detected and measured with the digital still camera (Figure 10).

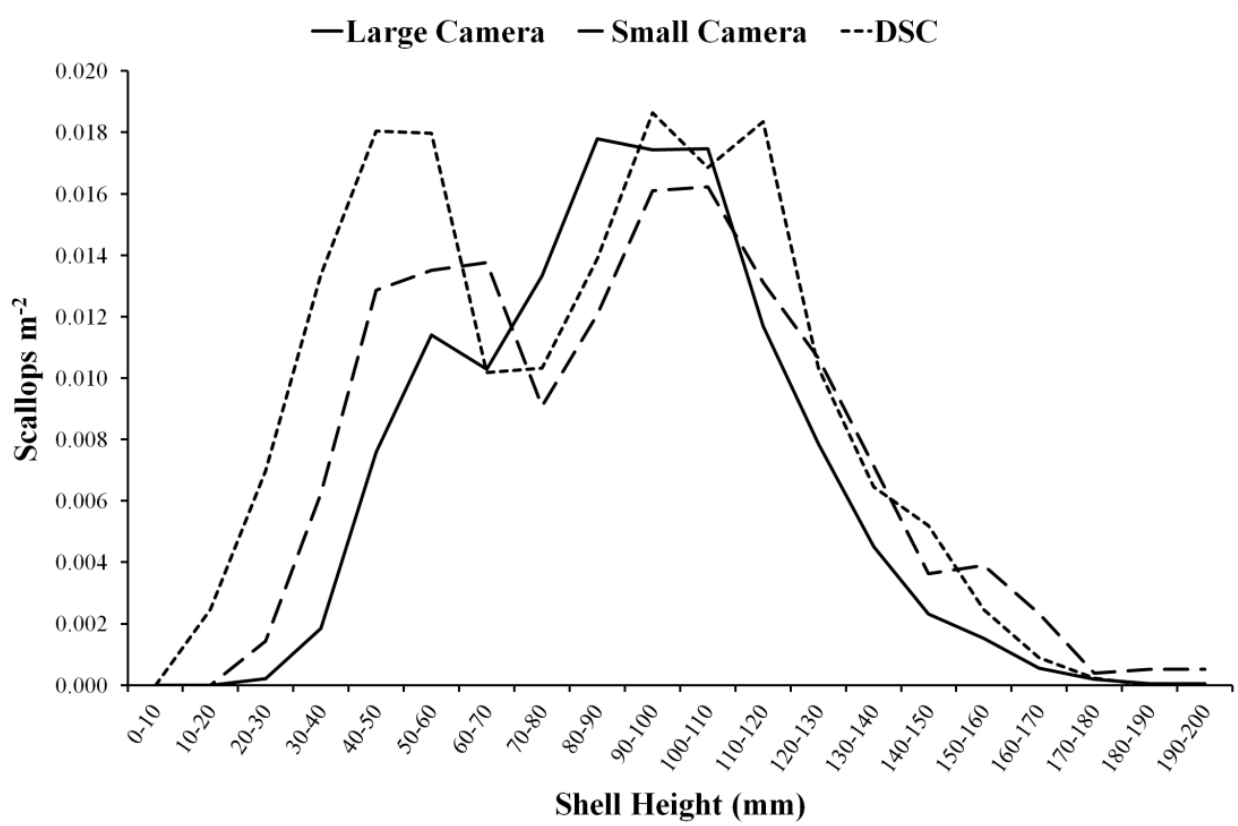

Figure 10. Density profiles by 10 mm shell height bin for the large camera, small camera and digital still camera (DSC); viewing area and measurement calibrations are presented in Table 1 of Carey and Stokesbury 2011.

Edge effect for video counts

Shell height adjusted camera view area modification analysis is presented in detail in Support Document 11 (O'Keefe et al., 2010). In summary, the view area of each camera was increased to account for scallops observed on the image boundary (Figure 11). The expanded view area was calculated by adding half the mean scallop shell height in the area being assessed to each edge of the quadrat using the equation:

(1) Edge Effect View Area Expansion

$$Expanded\ view\ area = \left(\text{height} + \left(2 * \left(\frac{meanSH}{2}\right)\right)\right) * \left(\text{width} + \left(2 * \left(\frac{meanSH}{2}\right)\right)\right)$$

We applied the ratio and camera view field adjustments to the drop camera survey data for the Mid Atlantic Bight and Georges Bank 5.6 km survey estimates from 2003 through 2009. We compared the original density estimates with the overall ratio adjusted estimate and the mean shell height adjusted camera view area adjustment (O'Keefe et al. 2010).

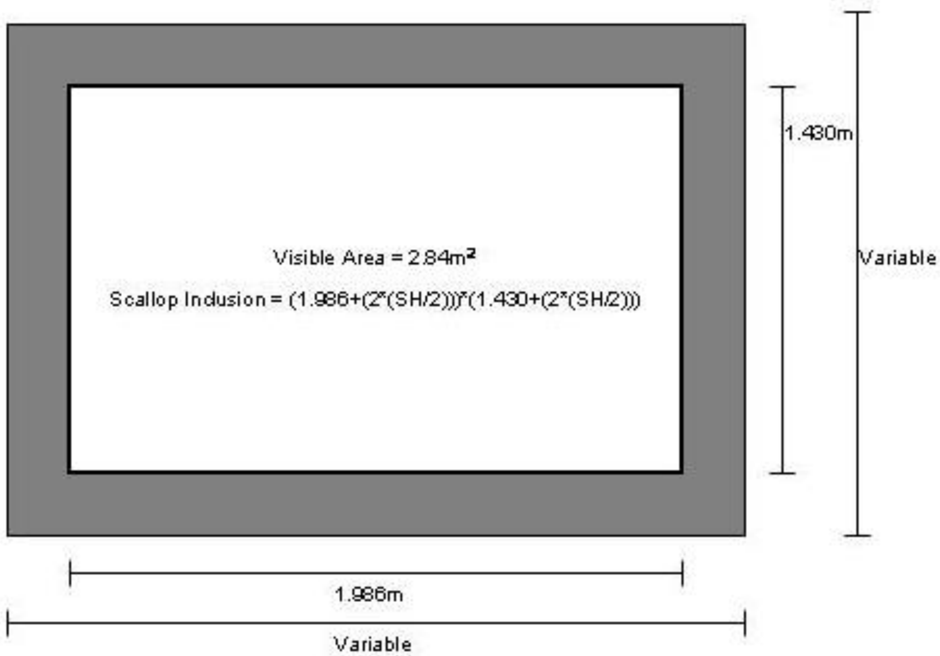

Figure 11. Camera view field used in calculation of mean shell height adjusted density.

Figure 12 shows a comparison of the original, yearly ratio adjusted, overall ratio adjusted and shell height adjusted density estimates for the Elephant Trunk closed area from 2003-2009. There were minimal differences in density estimates among all methods. The original method produced the lowest densities, especially when average scallop shell height was low. There was negligible difference between the yearly ratio adjusted and overall ration adjusted methods. The shell height adjusted method produced estimates that were on average 1-3% higher than the original method. This method was applied to all survey estimates made before the analysis and was accepted by the 50th SAW (NEFSC, 2010).

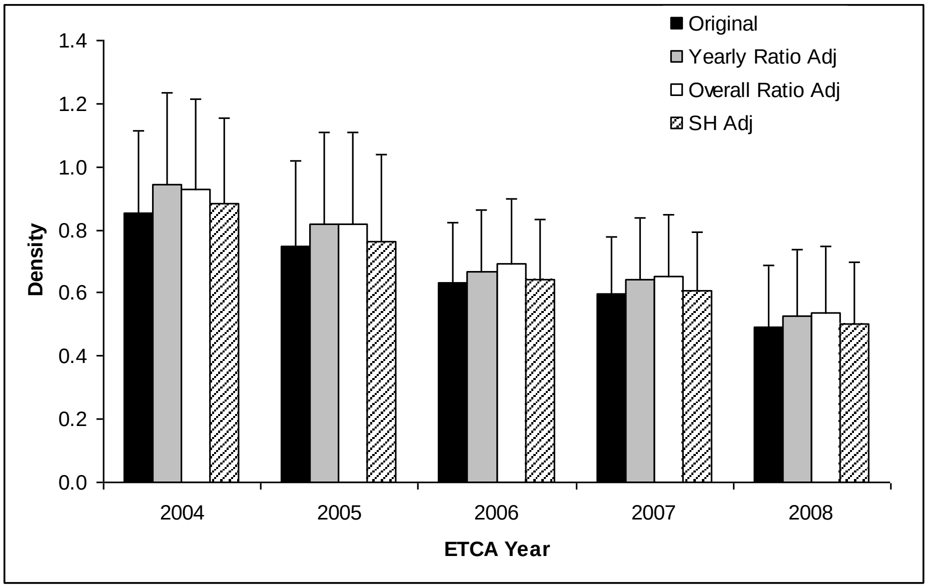

Figure 12. Density estimates from ETCA 2004-2008 with associated 95% confidence intervals.

ToR 3. Review the biological sampling aspects of the surveys, including sub-sampling procedures and the ability to sample all size classes. For each survey, evaluate the utility of data to detect incoming recruitment, assess the potential ability to assess fine scale ecology (e.g., Allee effect, predator-prey interactions, disturbance from fishing gear, etc.).

Biological sampling aspects of the survey, including sub-sampling procedures and the ability to sample all size classes are published in Stokesbury, 2002, and Stokesbury et al., 2004. The utility of data to detect incoming recruitment is published in Stokesbury et al., 2007, Carey and Stokesbury, 2011, Carey et al., 2013 (Support Document 12), Stokesbury et al., 2011 a,b and Stokesbury, 2012 (Support Document 13). The potential ability to assess fine scale ecology is published in Stokesbury et al. 2009 and 2010; Allee effect is published in Carey et al. 2013, predator-prey interactions is published in Stokesbury et al. 2004, Marino et al., 2007b, 2009 (Support Document 14); disturbance from fishing gear is published in Stokesbury and Harris, 2006 (Support Document 15), Stokesbury et al., in review. Here we focus on scallop recruitment, however several of the listed published papers are included as support documents and further information can be provide upon request.

The SMAST drop camera survey provides an estimate of scallop abundance, spatial distribution, size distribution and total and harvestable biomass in closed areas that may be open to fishing in the future and potential new closed areas. An example of the utility of the survey information is the basis for the proposed closed areas east of the Nantucket Lightship area and in the Mid-Atlantic. These areas were identified for protection of juvenile scallops with significant input from our 2014 broadscale survey (Figure 13). Extremely large recruitment events in 2003 (Stokesbury et al., 2004), 2009 (Stokesbury et al., 2010), and 2014 (Bethoney and Stokesbury, in review) were accurately identified by the SMAST drop camera survey (Figure 14). The tracking of predator changes in areas of large scallop recruitment is also possible using SMAST drop camera data due to the length of time the survey has been conducted and the quantification of approximately 50 animal groups (Figure 15; Marino et al., 2007b, 2009, Stokesbury et al., 2011 a,b).

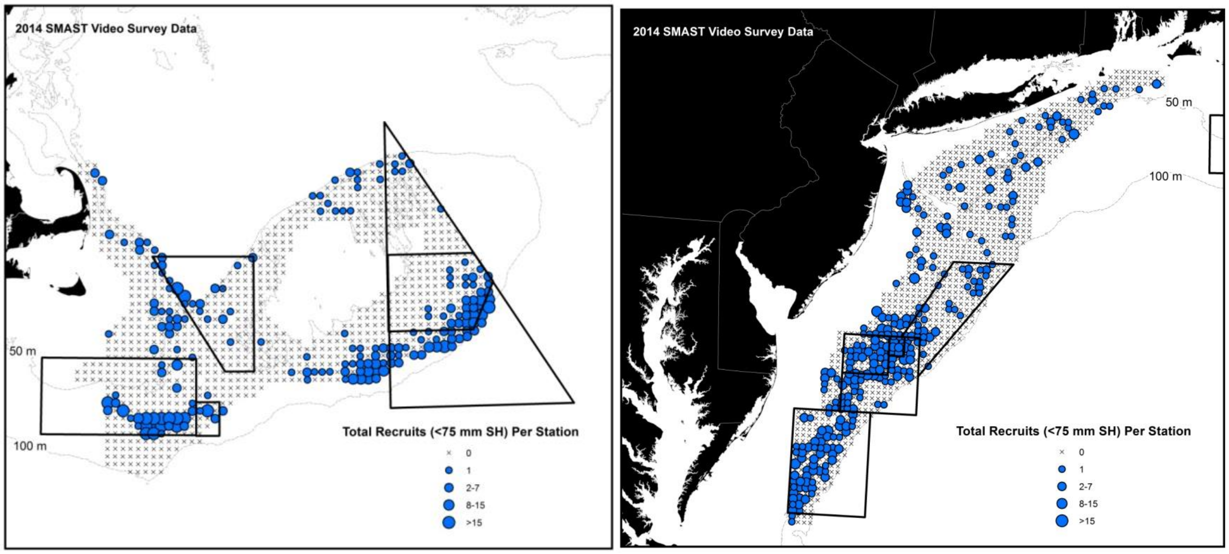

Figure 13. Distribution of scallop recruits (<75 mm) on Georges Bank (left) and the Mid-Atlantic (right) in 2014, with the closed areas and potential closed areas overlaid in black outline. These maps were requested by scallop PDT chair on 9 October 2014.

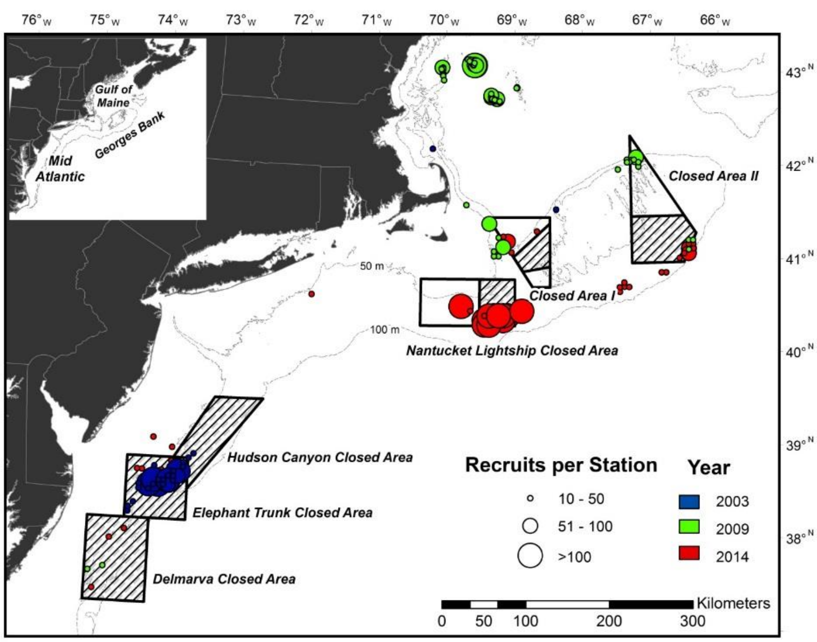

Figure 14. The number of recruits (scallops less than 75 mm shell height) observed by the SMAST drop camera survey in 2003, 2009, and 2014. Hatched marks identify portions of closed areas that are periodically open to scallop fishing.

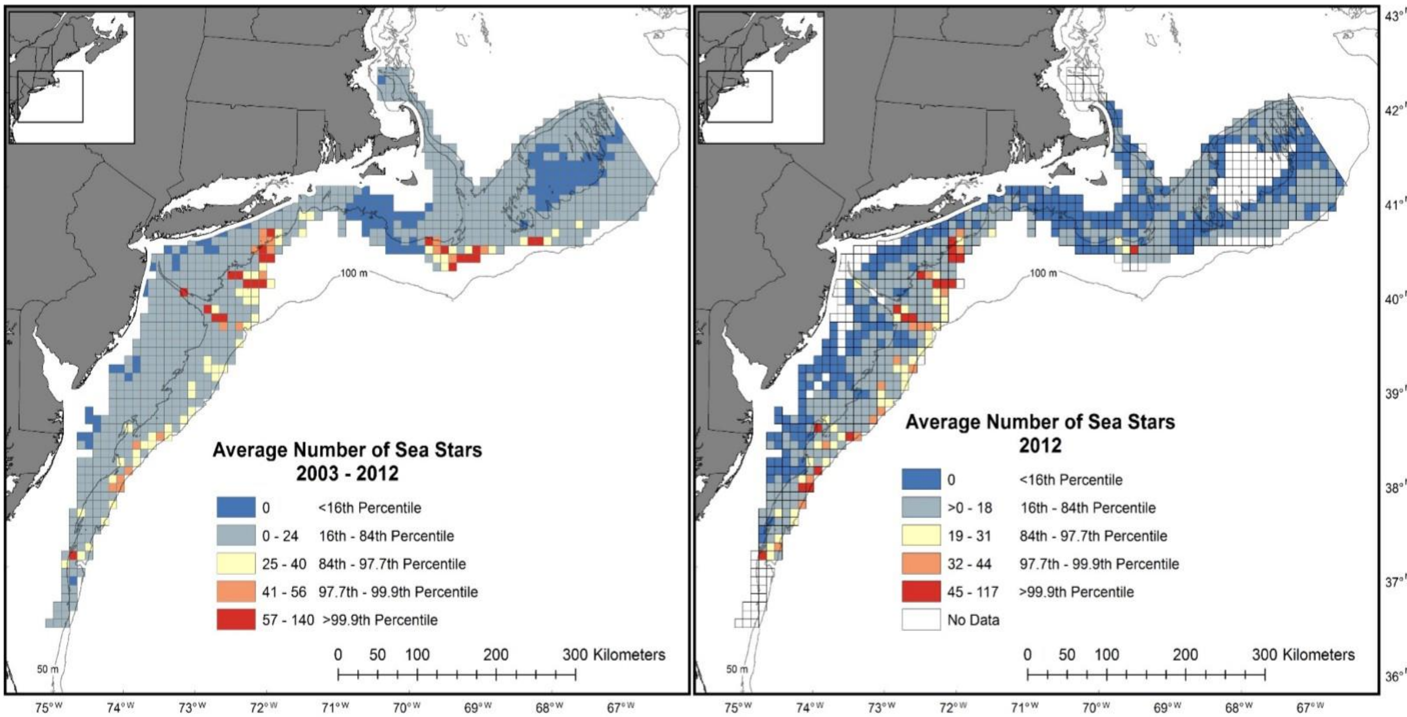

Figure 15. The average number of sea stars observed by the SMAST drop camera survey displayed on a portion of the Swept Area Seabed Impact model grid**.** In 2012, a large decline from the 10-year sea star number average on the southwestern part of Georges Bank is apparent. This area corresponds with a massive sea scallop recruitment event.

ToR 4. Review methods for using survey data to estimate abundance indices. Evaluate accuracy (measures of bias) of indices as estimates of absolute abundance.

The SMAST drop camera survey has successfully provided information on scallop density, spatial distribution total abundance and exploitable biomass for the scallop resource from 2003 to 2012 and in 2014 (Figure 17, Table 4). The survey is simple, flexible, cooperative with the industry and relatively inexpensive. It does not need the numerous calculations required to obtain absolute estimates from mobile sampling gear and the calculations and extrapolations that are required can be experimentally determined in a controlled environment (refer to ToR 2).

Calculation of basic statistics

As mentioned above, the camera view area is increased to account for scallops that lie on the edge of the image. This expansion was reviewed and accepted in the 50th SAW and is based on the average shell height of scallops in the area. The length and width of each image will be increased by the mean shell height of measured scallops within the survey area using the equation:

(2) $$Expanded\ View\ Area = (l + \overline{SH}) \times (w + \overline{SH})$$

where l and w are quadrat length and width and $\overline{SH}$ is mean shell height (O'Keefe et al., 2010; refer to ToR 2 and Support Document 11 for further details).

Mean densities and standard errors of scallops are calculated using equations for a two-stage sampling design (Cochran, 1977):

The mean of the total sample is:

(3) $$\bar{\bar{x}} = \sum_{i=1}^{n} \left(\frac{\bar{x}_i}{n} \right)$$

where n is the number of stations and $\bar{x}_i$ is the mean of the 4 quadrats at station i.

The SE of this 2-stage mean is calculated as:

(4) $$S.E.(\bar{x}) = \sqrt{\frac{1}{n}(s^2)}$$

where: $s^2 = \sum^{n} (\bar{x}_i - \bar{\bar{x}})^2 / (n-1)$.

According to Cochran (1977) and Krebs (1989) this simplified version of the 2-stage variance is appropriate when the ratio of sample area to survey area (n/N) is small. In this case, thousands of square meters (n) are sampled compared with thousands of square kilometers (N) in the study areas. All calculations use the number of scallops per square meter.

The absolute number of scallops in the survey areas are calculated by multiplying scallop density by the total area surveyed (Stokesbury, 2002). Estimates of scallop meat weight in grams (w) are derived from shell height (mm) frequencies collected during each survey and shell height to meat weight regressions used in the 50th SAW or as specified by the NEFMC Scallop PDT (NEFSC, 2010).

The equation for Mid-Atlantic scallops includes a shell height/depth interaction term, and the equation for Georges Bank scallops includes a latitude term.

(5) <u>Mid-Atlantic Shell Height: Meat Weight</u>

$$MeatWeight = exp[a + (b * \ln SH) + (c * \ln depth) + (d * \ln SH * \ln depth)]$$

Where: a = -16.88
b = 4.64
c = 1.57
d = -0.43

(6) <u>Georges Bank Shell Height:Meat Weight</u>

$$Meat\ Weight = exp[a + (b * \ln SH) + (c * \ln depth) + (d * \ln latitude)]$$

Where: a = 9.6771
b = 2.8387

c = -0.5084
d = -4.7629

The commercial scallop dredge selectivity equation is based on Yochum and DuPaul (2008):

(7) Commercial Scallop Dredge Selectivity

$$Selectivity = exp(-9.32 + (0.09 * SH))/(1 + exp(-9.32 + (0.09 * SH)))$$

Information on density, abundance, biomass and shell height from the SMAST drop camera survey have been evaluated, reviewed and incorporated in the NEFSC Northeast Regional Stock Assessment Workshops for sea scallops (Figure 16).

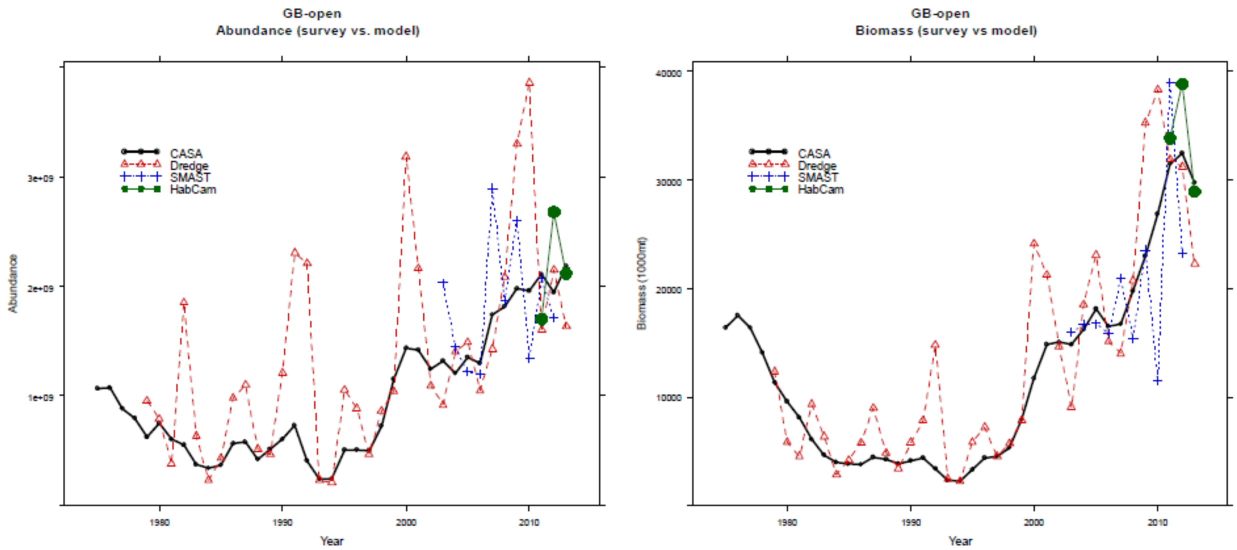

Figure B6.12. Comparison of CASA model estimated abundance (left) and biomass (right) with expanded estimates from the lined dredge survey (dashed red line with triangles), SMAST large camera survey (dotted blue line with crosses) and Habcam (solid line with circles) for Georges Bank open.

Figure 16. Graph from 59th SAW comparing SMAST to CASA models and other surveys of Georges Bank.

An example of annual data products:

The SMAST drop camera survey has successfully provided information on scallop density, spatial distribution total abundance and exploitable biomass from the scallop resource from 2003 to 2012 and in 2014 (Figure 17, Table 4).

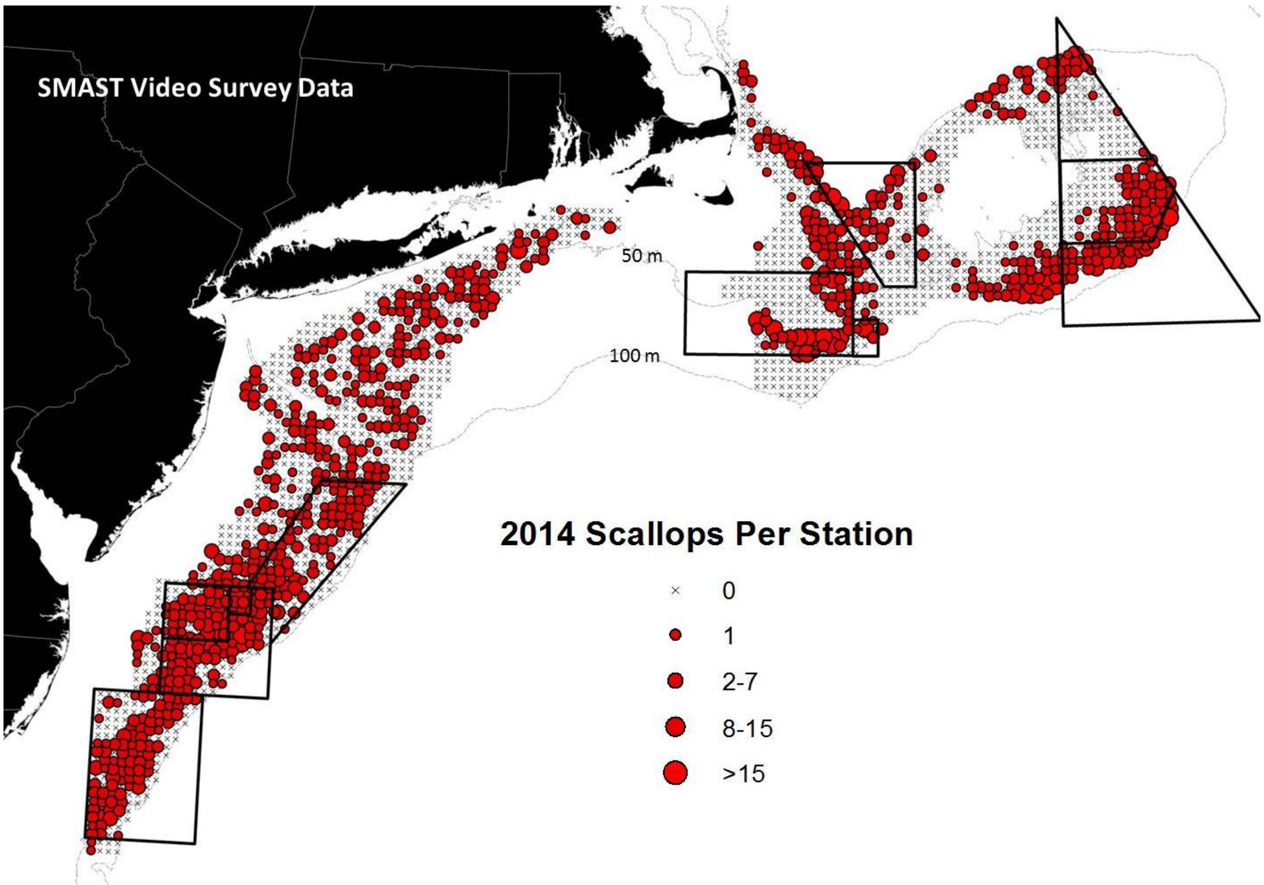

Figure 17. Scallop distribution on Georges Bank and the Mid-Atlantic from May to July 2014, presented to the SMAST Fishermen's Steering Committee on 4 August 2014 and submitted to the NEFMC and NEFSC on 20 August 2014.

Table 4. Summary data of the scallop stock status presented to the SMAST Fishermen's Steering Committee on 4 August 2014 and submitted to the NEFMC and NEFSC on 20 August 2014. A.) 2014 SMAST large camera video basic outputs. Included in the table is the quadrat area sampled (m^2), mean shell height of scallops observed (mm), number of scallop shell heights measured, mean number of scallops per m^2, number of stations sampled, standard error, coefficients of variance, and the total area of each specific survey area. B.) 2014 SMAST large camera video estimates of total and exploitable biomass for areas of Georges Bank and the Mid-Atlantic (MW = mean scallop meat weight (g), total weight of scallops in millions of pounds (LBS) and metric tons (MT) and the standard error in metric tons

A.)

Georges Bank	quad area	mean SH	# Measurements	per m2	stations	SE	CV%	Area km2
CAI Access	3.149	88.3	24	0.04	51	0.016	39.0	1574
CAI Closed	3.059	62.8	189	0.53	48	0.310	58.7	1482
CAI "Sliver" 1.5 nm	3.198	101.8	561	0.61	119	0.137	22.5	918
CAII Access	3.093	72.4	357	0.27	119	0.085	31.4	3673
CAII Closed	3.211	105.4	70	0.10	81	0.035	37.0	2500
GSC	3.073	67.0	284	0.29	149	0.202	70.5	4600
NEP	3.070	66.1	264	0.31	86	0.079	25.3	2655
NLCA Access	2.990	43.3	3460	5.53	79	1.203	21.7	2439
NLCA Closed	3.033	55.6	269	0.76	51	0.676	89.2	1574
Non-strata	3.115	78.7	31	0.01	239	0.003	22.0	7378
SEP	3.086	70.6	279	0.28	98	0.055	19.3	3025
Sum of areas					1001			30900

Mid-Atlantic	quad area	mean SH	# Measurements	per m2	stations	SE	CV%	Area km2
BItoLI	3.122	80.7	43	0.06	60	0.031	48.9	1852
DMCA	3.096	73.4	366	0.24	145	0.028	11.4	4476
ETCA	3.100	74.5	668	0.54	145	0.063	11.7	4476
HCCA	3.134	84.0	191	0.15	142	0.020	13.9	4383
LI	3.147	87.5	222	0.06	365	0.005	9.3	11267
Non-strata	3.033	55.5	25	0.04	72	0.014	35.2	2223
NYBS	3.120	80.0	92	0.07	132	0.009	13.7	4075
NYBSwStratum21	3.097	73.8	187	0.08	239	0.010	13.1	7378
Sum of areas					1168			36055

B.)

Georges Bank	Estimation of Total Biomass				Estimation of Exploitable Biomass			
	mean mwt	mill lbs	in mt	SE	mean mwt	mill lbs	in mt	SE
CAI Access	14.5	2	962	375.3	22.5	1	486	189.5
CAI Closed	6.5	11	5115	3003.6	19.7	7	3090	1814.7
CAI "Sliver" 1.5 nm	17.4	21	9708	2189.1	21.8	15	6647	1498.9
CAII Access	8.2	18	8197	2570.3	18.3	7	2963	929.1
CAII Closed	23.3	12	5550	2054.0	32.5	9	4191	1551.0
GSC	8.4	25	11134	7849.4	26.1	11	4949	3489.0
NEP	7.0	13	5863	1482.6	21.4	5	2259	571.4
NLCA Access	2.2	66	30052	6534.2	17.3	9	3891	845.9
NLCA Closed	4.4	11	5211	4649.8	20.5	2	758	676.8
Non-strata	13.0	3	1289	283.9	27.2	2	728	160.3
SEP	8.2	15	7026	1359.0	19.9	5	2476	479.0
Sum of areas		187	84991			65	29348	

Mid-Atlantic	Estimation of Total Biomass				Estimation of Exploitable Biomass			
	mean mwt	mill lbs	in mt	SE	mean mwt	mill lbs	in mt	SE
BItoLI	11.6	3	1372	671.0	18.0	1	521	254.5
DMCA	8.9	21	9626	1093.3	18.3	9	3935	447.0
ETCA	10.3	55	24799	2909.1	22.5	29	12938	1517.7
HCCA	11.4	16	7361	1020.7	17.4	7	3143	435.8
LI	16.0	23	10269	950.0	26.3	14	6402	592.3
Non-strata	4.3	1	379	133.6	12.7	0	57	20.2
NYBS	13.1	8	3609	494.6	27.5	5	2119	290.4
NYBSwStratum21	11.6	14	6520	856.8	31.6	9	3955	519.7
Sum of areas		133	60326			68	30951	

ToR 5. Evaluate any proposed methods for integrating and using surveys outside of a stock assessment model for management purposes.

Annual scallop harvest allocation:

Data from the SMAST drop camera survey has been provided to NEFMC and NMFS every year from 2003 to present, to support decision-making for annual harvest allocations levels and access to specific rotational areas. The information has been used and reviewed in Frameworks 12 (NEFMC, 1999a), 13 (NEFMC, 1999b), 16 (NEFMC, 2004), 18 (NEFMC, 2006), 19 (NEFMC, 2007a), 20 (NEFMC, 2007b), 21 (NEFMC, 2010) 22 (NEFMC, 2011b), 24 (NEFMC, 2013) and 25 (NEFMC, 2014).

Total and exploitable biomass estimates from the SMAST drop camera survey have been used to evaluate past performance of stock assessment estimates and annual fishery allocation levels. Stokesbury (2012) provided a time series of biomass estimates for the Georges Bank and Mid-Atlantic portions of the resource and compared annual fishery landings to the estimates of exploitable biomass based on a variety of fishing mortality reference points (Table 5; Figure 18). The combination of the extremely large number of small scallops in the Mid-Atlantic in 2003, a large amount of Georges Bank scallop biomass in partially and permanently closed areas, and a management strategy that applies a single fishing limit on the entire resource results in excessive fishing in the Mid-Atlantic Bight and an underutilization of the resource on Georges Bank based on optimum yield (Figure 18; Stokesbury, 2012 updated). This type of retrospective analysis of the management strategy, based on information from the SMAST drop camera survey, can be useful for evaluating future decision-making and determining the optimal management scenarios for the scallop resource.

Table 5. Estimated average biomass (MT, meat weight) and 95% confidence limits for the US offshore scallop resource on Georges Bank and in the Mid-Atlantic Bight from 2003 to 2014 using the SMAST drop camera system, large camera quadrats; ~ 2,000 stations sampling 7,200 2.8 m^2 quadrats annually (updated from Stokesbury, 2012); note that there was no SMAST broad scale survey was conducted in 2013.

	Georges Bank		Mid-Atlantic	
Year	Average	±95% CL	Average	±95% CL
2003	88,075	13,650	108,581	35,195
2004	82,428	19,127	78,613	15,065
2005	75,793	17,199	84,771	19,678
2006	90,205	18,763	76,338	14,808
2007	86,197	18,619	78,756	13,791
2008	47,562	8,105	83,590	16,284
2009	71,346	15,296	63,596	7,751
2010	81,944	16,093	62,626	10,870
2011	82,237	19,429	63,872	8,044
2012	70,455	18,661	33,390	6,431
2014	86,696	38,301	59,605	8,115

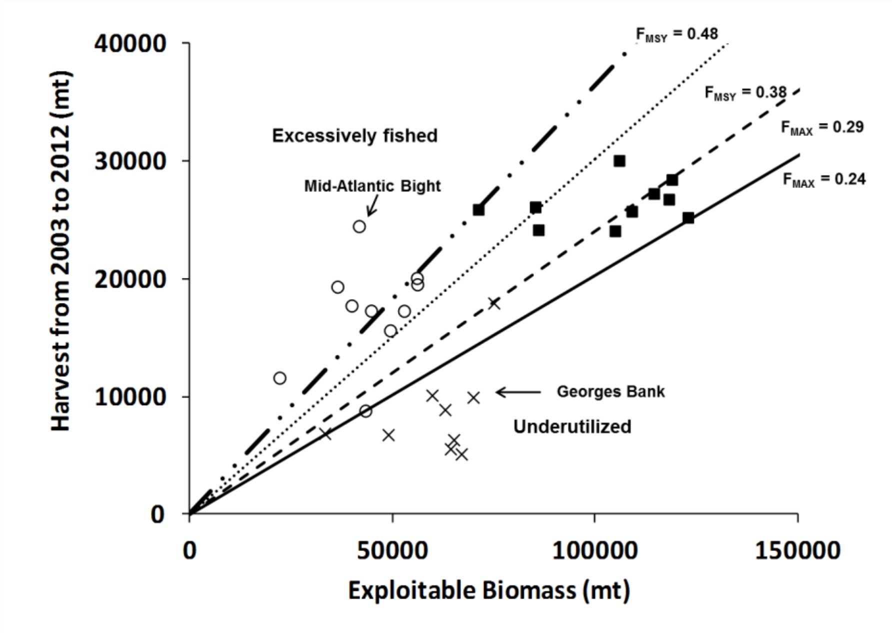

Figure 18. Comparison of the scallop harvest to the SMAST video estimated exploitable biomass (both are meat weights in metric tons) for Georges Bank (×) and the Mid-Atlantic Bight (○) and the entire resource (■) from 2003 to 2011. The estimated optimum yield curves for 2003 to 2007 (F_{MAX} = 0.24) proposed 2008 (F_{MAX} = 0.29), the 2010 F_{MSY} = 0.38 and the 2014 F_{MSY} = 0.48 are also represented (NEFMC, 2004, NEFSC, 2007b, NEFSC, 2010, NEFSC, 2014).

Access area monitoring

Data collected from the SMAST drop camera survey is used to estimate the abundance and biomass of scallops within access areas. Tracking scallop populations within the rotational areas is an important component of scallop fishery management. Biomass data are used to calculate the number of trips and trip limits to be allocated to the scallop fishing fleet. Accurate estimates of biomass within access areas is required to ensure that optimal yield is obtained, while preventing overfishing. Further, the SMAST drop camera survey can be used to non-invasively evaluate scallop populations within closed or potential access areas. Between 2004 and 2005 the video survey identified a mass scallop mortality (Stokesbury et al., 2007). The survey is also being used to evaluate the changes in the scallop populations within the small scale Muscle Ridge closed and limited access areas in the Gulf of Maine. Intensive, industry-based surveys of access areas, or areas that may be candidate access areas in the future, were given the “Highest Priority” in the 2015 Sea Scallop RSA Program needs.

Recruitment event monitoring

The flexibility and non-invasive nature of the SMAST drop camera survey makes it an ideal method for identifying and monitoring recruitment events. The Scallop PDT recently created alternatives that expand the Closed Area II and Nantucket Lightship access areas to protect juvenile scallops, SMAST data were utilized to help formulate the proposed closures (Figure 13). In response to the 2015 RSA call for proposals we proposed to conduct a survey that would define the extent of the juveniles observed from 2012 to 2014, and provide biomass estimates in this area, as requested by the Scallop PDT. It would allow managers to track the status of juveniles, which could help avoid the wasteful situation that occurred between 2003 and 2004, when 10.4 billion 30 to 80 mm shell height sea scallops disappeared in the Mid-Atlantic. Strong evidence suggests that incidental fishing mortality, allowed due to delayed closure of the Elephant Trunk Area, resulted in this loss (Stokesbury et al., 2011a,b). Alternative views, suggest this loss was a result of crab predation (Hart and Shank, 2011). This uncertainty emphasizes the need to continually, intensively monitor massive juvenile scallop aggregations until they reach harvestable size. To avoid missing scallop beds, surveys in Closed Area II and the Nantucket Light Ship Closed Area should have a resolution no greater than 3 km between each station (Adams et al., 2010). Given this sampling intensity and the adverse effects of dredging and discarding juvenile scallops, non-invasive video surveys may be better suited for repeated, high-intensity observations of juvenile aggregations.

Meat quality and disease monitoring

Results from an SMAST project investigating the occurrence of gray meat in Atlantic sea scallops found the primary cause to be a newly identified apicomplexan parasite that targets muscle tissue in the animal. Closing areas to fishing for extended periods potentially increases the densities and size class of scallop populations. We currently do not know the range of this parasite or how biotic and abiotic conditions affect the host parasite balance. Video footage from locations of high gray meat occurrence provides data on environmental variables or visual cues (such as the presence of specific growths/epifauna) that may be correlated with gray meat outbreaks. Monitoring, and tracking the occurrence of gray meat scallops could be utilized to refine calculations of exploitable yield (modification of the shell height / meat weight) and optimize rotational management based on the proportion of scallops effected by the parasite (estimation of the proportion of exploitable scallops that are marketable). Understanding the distribution of gray meats could also aid in the estimation of scallop discards.

ToR 6. Comment on potential contribution of each survey to assessments for non-scallop species and use of data apart from assessment purposes such as characterizing species habitat, understanding sea scallop ecology, and ecosystem studies.

A high resolution substrate map of Georges Bank using SMAST drop camera survey data was published in Harris and Stokesbury, 2010 (Figure 19, Support Document 16). This map increased the information on surficial sediment characteristics on Georges Bank by several orders of magnitude and has been widely requested and used since its publication, the supporting data was published in the archives of *Continental Shelf Research*.

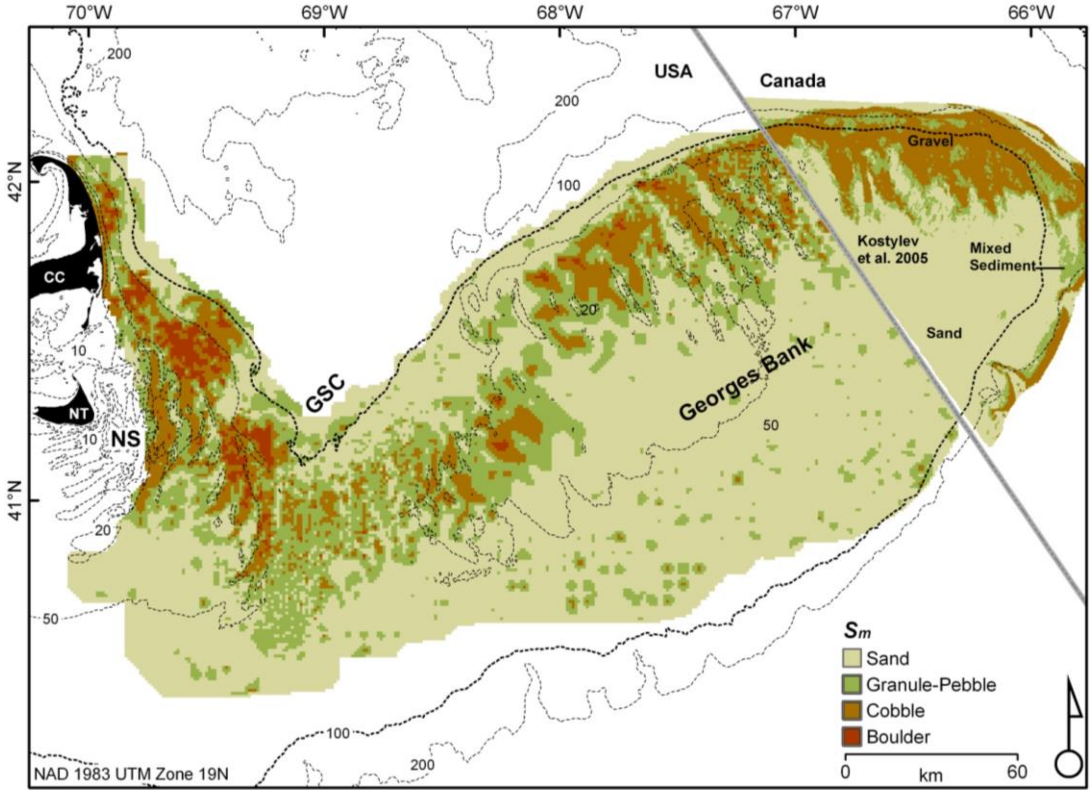

Figure 19. High resolution map of the largest sediment types present (Sm) on Georges Bank and multi-beam acoustic map of dominant sediments from Kostylev et al., (2005) for the Canadian side (Figure 9 from Harris and Stokesbury, 2010).

Data from the SMAST drop camera survey have contributed in numerous ways to the assessment of non-scallop species, characterization of habitat, and understanding scallop ecology and ecosystems. The density, distribution, and abundance of sea stars (Marino et al., 2007b, 2009), skates (MacDonald et al., 2010), lobsters, and crabs have been estimated using SMAST survey data. Further, a current PhD dissertation is focusing on describing echinoderm populations on Georges Bank. The first chapter describes the spatial and temporal patterns of distribution and abundance of brittle stars, sand dollars, sea stars, and sea urchin *spp*. (Figure 20). Through an ongoing collaboration with The Nature Conservancy, annual and decadal animal distribution maps are being created based on data from the largest camera view for the 12 most frequently observed animal groups in the survey (Figure 15, Table 6). The data used to create these maps will be uploaded to the Northeast and Mid-Atlantic data portals to facilitate public access.

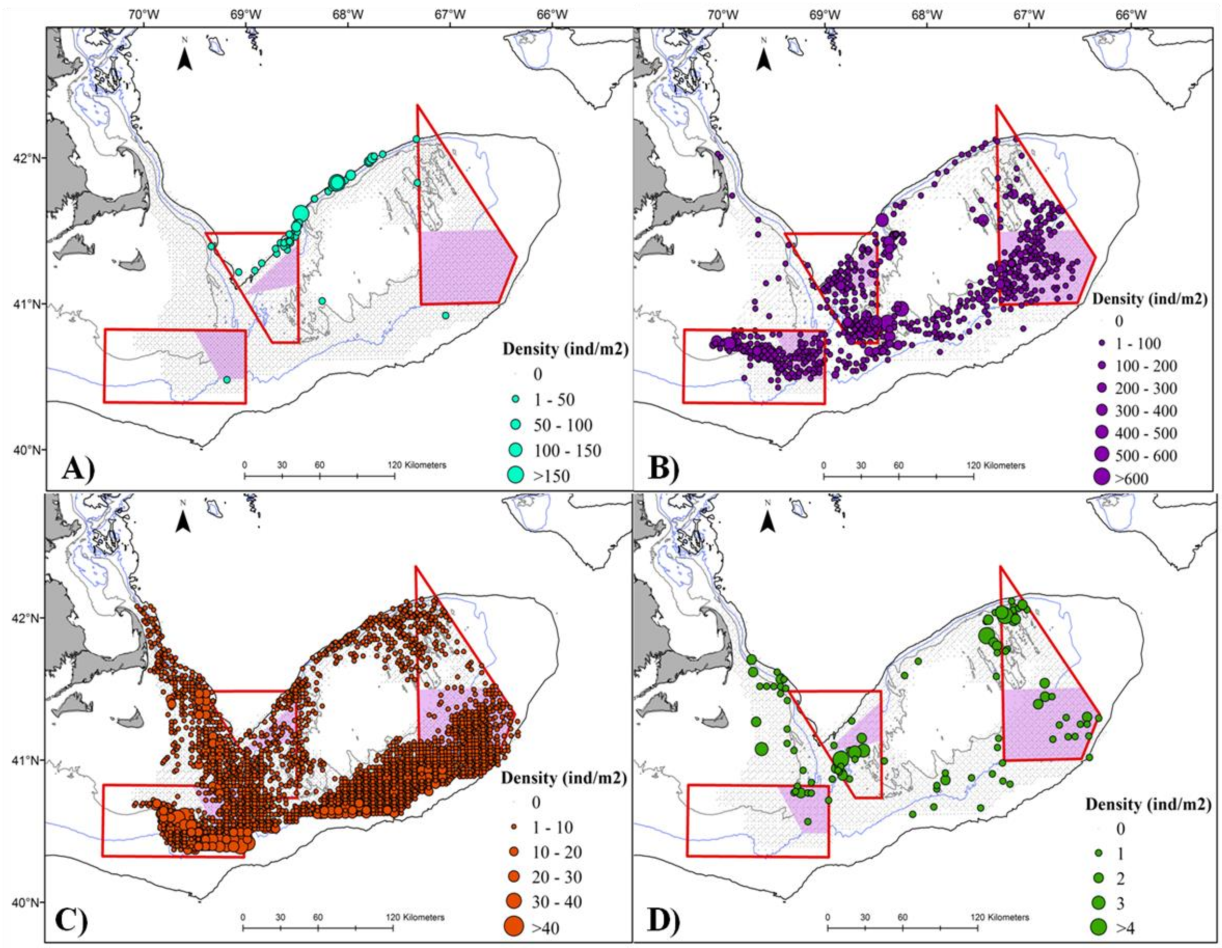

Figure 20. Distribution and density of A) brittle stars, B) sand dollars, C) sea stars, and D) sea urchins from 2005 to 2012. Red polygons represent Marine Protected Areas. Purple shaded areas identify portions of closed areas that are periodically open to scallop fishing.

Table 6. The 12 most frequently observed animal groups, in order of most to least observed, in the SMAST drop camera survey data set.

Animal Group
Sea Stars
Sea Scallops
Bryozoan/Hydrozoa
Sand Dollars
Hermit Crabs
Skates
Sponges
Red Hake
Moon snails
Crabs
Flatfishes
Burrowing species (holes)

SMAST drop camera survey data have been used to characterize benthic habitat and assess the impact of fishing. Between 1999 and 2014 the SMAST drop camera survey repeatedly sampled the continental shelf from Norfolk Canyon north to the banks and ledges of the Gulf of Maine (total area = 918,876 km^2). In each video image collected, sediments were visually identified following the Wentworth particle grade scale, where the sediment particle size categories were based on a doubling or halving of the fixed reference point of 1 mm; sand = 0.0625 to 2.0 mm, gravel = 2.0 to 256.0 mm and boulders > 256.0 mm (Wentworth, 1922, Lincoln et al., 1992). Gravel was divided into two categories, granule/pebble = 2.0 to 64.0 mm and cobble = 64.0 to 256.0 mm (Lincoln et al., 1992). This information was used to map the spatial structure of substrate characteristics and seabed disturbance on Georges Bank (Figure 19 and Harris et al., 2010) and over the whole domain. This new sediment and natural disturbance data along with new geological and biological feature weightings for the Gulf of Maine, Georges Bank and the Mid-Atlantic Bight were provided to the New England Fisheries Management Council's Habitat PDT to update the Swept Area Seabed Impact model (Figure 21). This research was developed and conducted with direct input from the New England Fisheries Management Council's Habitat/ Ecosystems/ Marine Protected Area Plan Development Team. The Swept Area Seabed Impact model is a new quantitative tool for evaluating fisheries management alternatives by examining the tradeoffs between habitat impacts and fishery yields. Data from the survey was also used to directly assess the impact of scallop dredging on the epibenthic community (Stokesbury and Harris, 2006, Stokesbury et al., in review) and to define habitat characteristics and spatial distribution of benthic marine invertebrates and some fishes in potential wind energy areas off the coasts of Maryland (collaborative project with NOAA and the NEFSC through the Cooperative Institute for the North Atlantic Region) and southern New England (funded by the Bureau of Ocean Energy Management).

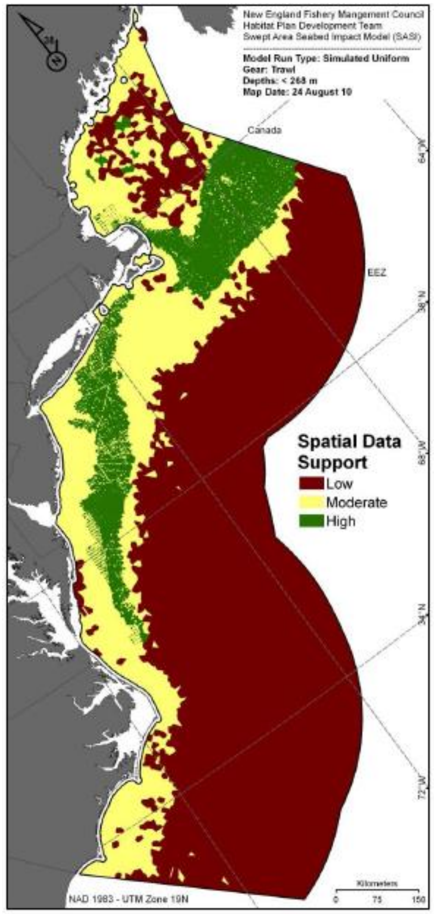

Figure 21. Map 24 from the New England Fisheries Management Council Essential Fish Habitat Omnibus Amendment (2011) depicting the spatial data support for the Swept Area Seabed Impact model. The areas of high spatial data support correspond to the SMAST scallop survey footprint.

Apart from assessment purposes, several specific projects using SMAST drop camera survey data have contributed to understanding scallop ecology and benthic ecosystems. The fine scale distribution and crowding levels of juvenile and adult scallops were examined using data from the high resolution digital still camera (Carey et al. 2013). A Master's degree project examining benthic species assemblages associated with scallops on Georges Bank is underway. SMAST drop camera survey data from the central Gulf of Maine in 2009-2014 is currently being used to estimate the natural mortality rate of sea scallops and to determine benthic community structure on Jefferys Ledge, Fippennies Ledge, Cashes Ledge, and Platts Bank. Community structure change in these areas will also be assessed by comparing current observations with observations made 30 years ago (Langton and Robinson, 1990). Analysis of the environmental and biological factors (depth, sediment stability, sediment type, temperature, and predator/prey abundance) that could delineate the preferred habitat conditions for echinoderms on the benthos of Georges Bank is also underway as part of a PhD dissertation. Direct associations between benthic species observations and environmental data can be made using the temperature-depth logger that has been attached to the drop camera pyramid since 2008**,** which records measurements every thirty seconds providing a water temperature profile for each station. This profile not only provides observed bottom temperatures, but also the temperature in the water column providing information on stratification or mixing in the environment that influences nutrient cycling and ecosystem attributes. The drop camera pyramid can also provide a stable platform for other instrumentation including flow meters, light and salinity recorders.

ToR 7. Comment on the current and/or any proposals for optimal frequency and combination of survey methods.

SMAST Sled dredge:

The SMAST sled dredge was created to provide biological samples of the sea scallop resource and its associated habitat in conjunction with the drop camera survey. During two survey trips on Georges Bank, the sled dredge and drop camera pyramid were deployed from the same vessel, successfully collecting both video data and biological samples from 25 stations. Modifications to the dredge included reducing the ring size, added sediment traps, lights and cameras, and a temperature-depth logger (Star-Oddi DST milli-TD). Biological samples collected concurrently with the video survey may confirm size frequency, density and substrate type throughout these areas (Figures 22, 23, Table 6). Though a dredge liner was not used in the first survey (Figure 22), video footage of small scallops evading the dredge suggest that the video survey images better quantify the amount of small scallops on the sea floor. Results from the second survey, in which a dredge liner was used, support this conclusion (Figure 23).

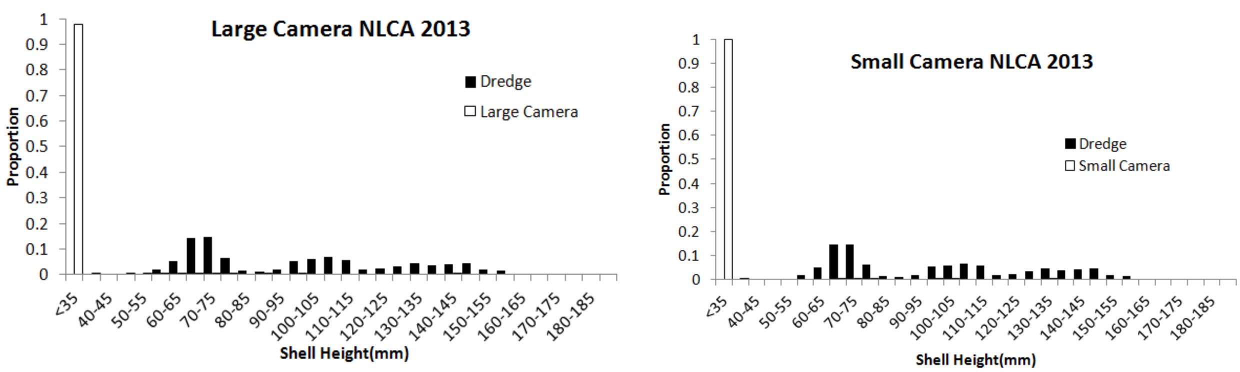

Figure 22. Proportion by 5mm shell height bin for large and small camera with dredge tows in Nantucket Lightship Closed Area (NLCA).

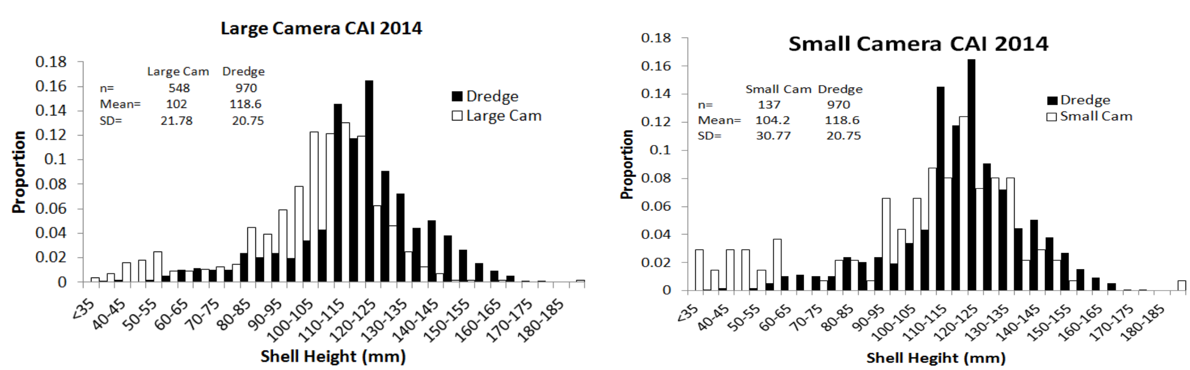

Figure 23. Proportion by 5mm shell height bin for large and small camera with dredge tows in Closed Area I (CA I).

Table 6. Comparison of maximum (S_{MAX}) and average (S_c) sediment types observed in similar areas by drop camera survey and dredge sediment trap sampling techniques in the Nantucket Lightship Closed Area.

Drop Camera	Dredge	Drop Camera	Dredge
S_{MAX}	S_{MAX}	S_c	S_c
sand	sand	smooth	smooth
gravel	gravel	intermediate	smooth
sand	gravel	smooth	smooth
sand	sand	smooth	smooth
sand	sand	smooth	smooth
sand	sand	smooth	smooth

Near shore dive comparisons:

In the fall of 2013 and 2014, the SMAST drop camera survey successfully surveyed the Muscle Ridge area of inshore southeastern Maine on a 0.2 km grid. This survey was conducted in collaboration with an on-going SCUBA dive quadrat study to estimate benthic macroinvertebrate community and substrate habitat, as well as total and exploitable biomass of sea scallops. This collaborative study with the Hurricane Island Institute and local fishermen could result in the comparison of diver collected data to drop camera data.

ToR 8. Identify future research and areas of collaboration among investigators and institutions.

Future Research

The SMAST drop camera survey is always a cooperative Industry/research survey, and collaborations between SMAST and other institutions have increased over the past few years In 2012 and 2013, we used the SMAST drop camera survey to examine the benthic macroinvertebrate community and substrate habitat in the area proposed for offshore windfarm leasing in collaboration with the Bureau of Ocean Management and the Massachusetts Executive Office of Energy and Environmental Affairs. In addition, SMAST collaborated with the NOAA's James J. Howard Marine Sciences Laboratory in Sandy Hook, New Jersey and the NEFSC to survey a potential wind energy area off the coasts of Maryland and Delaware in 2013. SMAST also recently partnered with the Hurricane Island Institute and local fishermen to survey inshore Gulf of Maine (see ToRs 5, 6, 7 for more information about these projects).

Collaboration with other institutions also exists through our graduate student's research. Since 2006, seven Masters and one PhD student have graduated from SMAST using data from the drop camera survey to support their research. Currently there are four Masters and one PhD student using the drop camera data in their research. Through these thirteen students, eight NMFS/NEFSC scientists and five scientists from other universities have become adjunct faculty at the University of Massachusetts Dartmouth by serving as thesis committee members. A list of these students, their theses titles, and committee members is provided in Support Document 17.

Areas of collaboration with other survey methods

Collaboration between dredge and video survey techniques in areas of recruitment or areas of potential senescence could be beneficial to scallop management and stock assessment. As outlined in ToR 5 the adverse effects of dredging and discarding juvenile scallops suggests that non-invasive video surveys may be better suited for repeated, high-intensity observations of juvenile aggregations. However, limited dredging would be beneficial to assess scallop meat quality especially if the distribution of the juvenile scallop aggregation extends into areas of less suitable scallop habitat. Similarly, combining methods in areas where scallops may be suffering from the effects of senescence or disease would allow for low impact, high intensity surveys that have the ability to assess meat quality, potentially avoiding wasteful scenarios (Stokesbury et al. 2007). Additionally, as described in ToR 7, combining survey methods in specific areas allows for comparison between the two methods to identify the strengths and weaknesses of each approach. For example, past comparisons between surveys using commercial or research dredges (Virginia Institute of Marine Science, NEFSC) and the SMAST drop camera survey have yielded information about dredge and camera selectively that improved scallop stock assessment (see ToR 2).

Combining optical surveys in potential wind energy areas could provide a comprehensive baseline for determining the impact of developing offshore renewable energy. An example of this was the assessment of benthic habitat in the Maryland-Delaware wind energy area, which utilized both the NEFSC Habcam and the SMAST drop camera to produce a multi-scale benthic assessment of the area. In addition to producing an extensive amount of information for the area, the collaboration also allowed for comparison between the two methods. Further detail about this project through the final report can be made available upon request.

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